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CORROSION PROBLEMS IN THE CANADIAN MARITIME FORCES

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Defence Research Establishment Atlantic

Centre de Recherches pour la Défense Atlantique

Canada

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Canada

Edited version of an oral presentation given at the Seventh Inter-Naval Corrosion Conference, Canberra, Australia, 10 April 1984.

ABSTRACT

from p. 1

Investigations of corrosion related failures that have taken place on Canadian naval ships are described. The investigations are divided into three categories: Machinery, Seawater Systems and General. The Machinery category includes examples of corrosion problems with desuperheater tubes, gas turbine engine fuel manifolds, and waste heat and auxiliary boilers. The Seawater Systems category describes the erosion corrosion of copper nickel pipes and pump impellers, and the crevice corrosion of a pump shaft. The General category includes corrosion problems with hulls and fasteners.

All of the corrosion problems described can be eliminated or reduced a significant degree using modern corrosion control practices.

RESUME

Description d'enquêtes concernant des pannes dues à la corrosion à bord de navires de la marine canadienne. Les enquêtes sont regroupées sous trois catégories: les machines, les installations d'eau de mer et les installations diverses. La catégorie "machines" porte sur des problèmes de corrosion comme ceux des tubes désurchauffeurs, des collecteurs de carburant des turbines à gaz et des chaudières auxiliaires et de récupération des gaz perdus. La catégorie "installations d'eau de mer" décrit les problèmes de corrosion par l'eau de mer des tuyaux de nickel-cuivre et des hélices de pompes ainsi que de corrosion fissurante d'un arbre de pompe. La catégorie "installations diverses" comprend des problèmes de corrosion des coques et des accessoires.

On peut éliminer ou réduire dans une grande mesure les problèmes de corrosion présentés en utilisant les pratiques modernes de contrôle de la corrosion.

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1. INTRODUCTION

The wastage of metals due to corrosion is one of the most serious engineering problems today and is of great economic concern[1,2,3]. The Canadian Navy is very sensitive to the problems of corrosion and the importance of corrosion control not only because of the costs incurred but also because of the potential detrimental effects on the operational capabilities of the ships and the safety of the crew. → p ii

One of the basic ship design philosophies that should be adhered to is that all structural components, machinery, and electrical systems will at some time or other be exposed to the marine environment. The corrosion engineer should be consulted early in the design stage when material selection is being considered. With the myriad of alloys available today, one cannot expect the design engineer to have an indepth knowledge of the properties of alloys and how they will withstand either continuous or intermittent exposure to the marine atmosphere.

One danger that the Canadian Navy faces which leads to corrosion problems is the purchase of off the shelf items intended for industrial use. Small quantities of marinized versions are either impossible or extremely expensive to purchase. For example, a pump that is used for fresh water in industry may have a stainless steel shaft. The shaft material would have to be changed if the pump was to be used for seawater service.

Material substitution by suppliers also leads to corrosion problems. The personnel in the supply system have no way of knowing (or the time to find out) if the substitution is in fact satisfactory. Substitution also occurs between the supply system and the ships. A ship may have to accept steel bolts for copper alloy flanges, due to operational commitments, knowing full well it has the wrong material. However, once the bolts are installed and either painted or lagged, they are forgotten.

One area that can be improved upon without too much difficulty is in the communication of corrosion problems to the proper authorities. It is a generally accepted belief that a number of corrosion problems are not reported by ships' staff. Rather than wading through the time consuming but necessary paper work, the items are simply repaired or replaced.

The further step in the process of eliminating a corrosion problem can sometimes be the most frustrating. Once the problem has been identified and a solution has been found, it can be very difficult to have the recommendations acted upon. It is necessary to get the recommendations to the design authority or the proper life cycle manager and convince this person that material changes are necessary. The onus is on the corrosion engineer to ensure that the recommendations are practical and cost effective.

It has been stated many times that the majority of corrosion problems can be solved by using generally accepted corrosion control practices. It would be possible to significantly reduce the costs of corrosion and improve the operational capabilities of the fleet, if these practices were impressed upon the design authority, the supplier, the stores system and the eventual user. More emphasis should be directed towards corrosion training at all levels, rather than focusing on corrosion failure analysis as the solution.

This paper discusses some corrosion problems that have been encountered by DREA over the last few years and the recommendations that have been made to solve them. The case histories are divided into three categories: machinery, seawater systems and general.

2. MACHINERY

2.1 Solar Saturn Fuel Manifold

Solar Saturn gas turbines are used to provide auxilary power onboard the DDH 280 Tribal Class destroyers. During a post engine failure inspection a crack was found in one of the tubes of a fuel manifold (Figures 1 and 2). This unit distributes the fuel to the burner nozzles in the gas turbine.

The fuel manifolds are made of stainless steel (UNS S34700). The surrounding operating temperature is approximately 350°F. A macroscopic examination of the inside of the cracked tube showed the presence of numerous microcracks that contained chlorides (Figure 3). Seawater, the source of chlorides, is an inevitable contaminant which enters the fuel tanks through faulty valves. It is normally removed from the fuel through gravity, centrifuges and coalescers.

A fractographic examination of the surface of a through thickness crack revealed a transgranular fracture morphology, characteristic of chloride stress corrosion cracking[3].

An investigation into the operation of the fuel transfer system revealed that the coalescer units had not been installed properly and that seawater was not being removed from the fuel. This problem was corrected and there have been no further failures of the fuel manifolds.

2.2 Desuperheater Tubes

Another problem has been the cracking in the desuperheater tubes in two AOR ships: HMCS Preserver and HMCS Protecteur (Figure 4).

An inspection of the tube bundles revealed cracking in a number of areas on the tubes. Cracks were found near welded tube ends, in areas where changes occured in the tube diameter, and at 90°bends (Figures 5, 6 and 7).

These desuperheater tubes are made of austenitic stainless steel (UNS S30400) and have been in use for approximately 17 years. A metallographic examination revealed that the tubing had experienced some degree of sensitization. The resulting carbide precipitation occuring along grain boundaries and at slip lines can be seen in Figure 8.

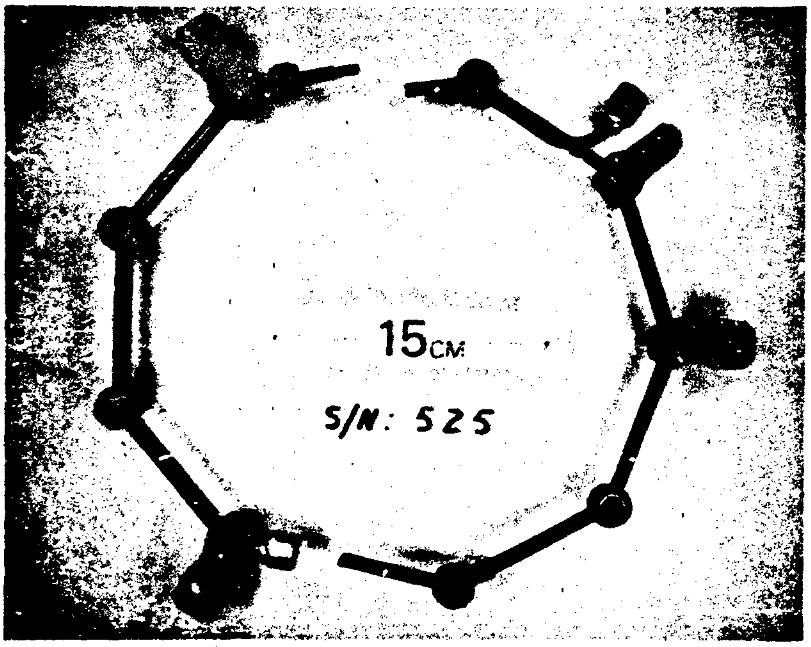

Figure 1 Cracked stainless steel Solar Saturn fuel manifold.

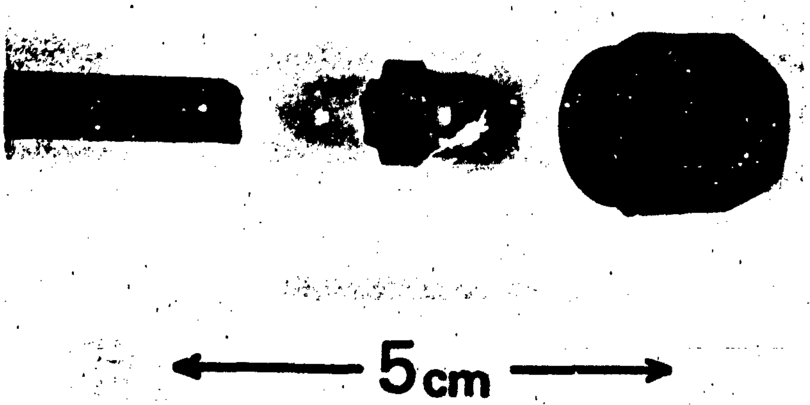

Figure 2 Section of stainless steel fuel manifold that failed near end fitting.

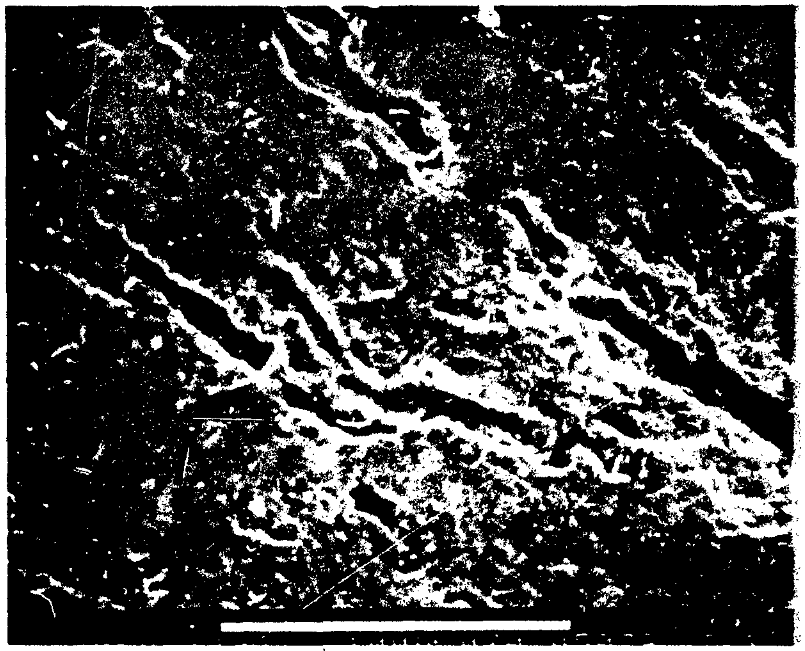

Figure 3 SEM micrograph of microcracks on inside of stainless steel fuel manifold. X492

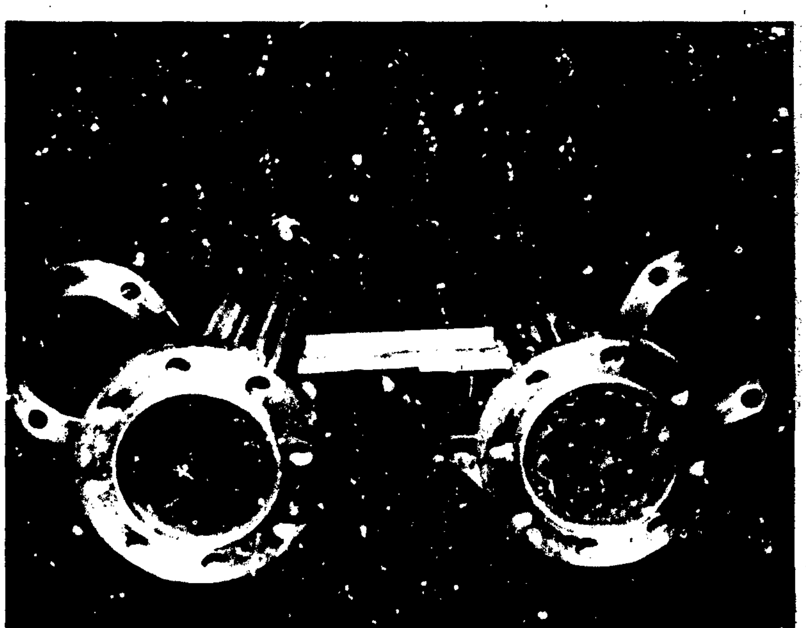

Figure 4 Austenitic stainless steel desuperheater tube bundle.

Figure 5 Cracks in welded stainless steel desuperheater tube ends.

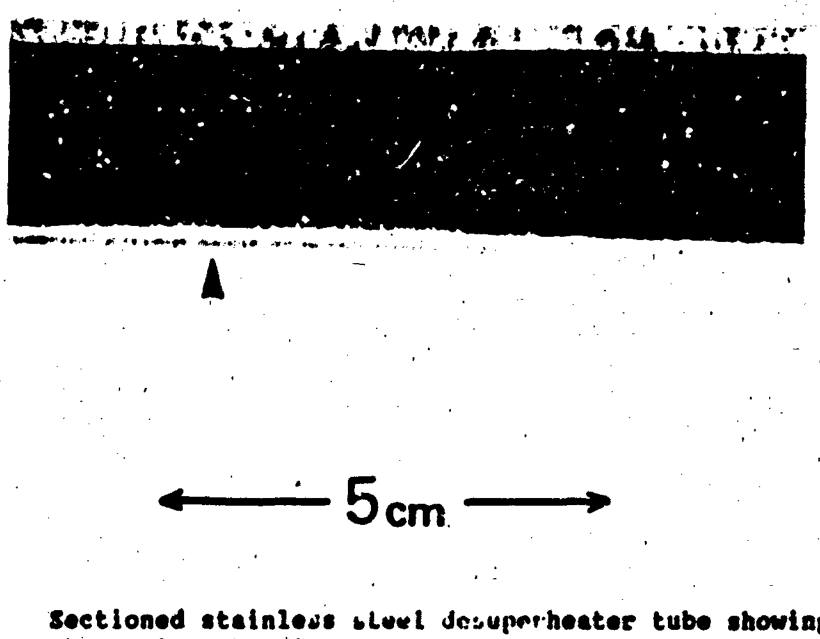

Figure 6 Sectioned stainless steel desuperheater tube showing crack near change in tube diameter.

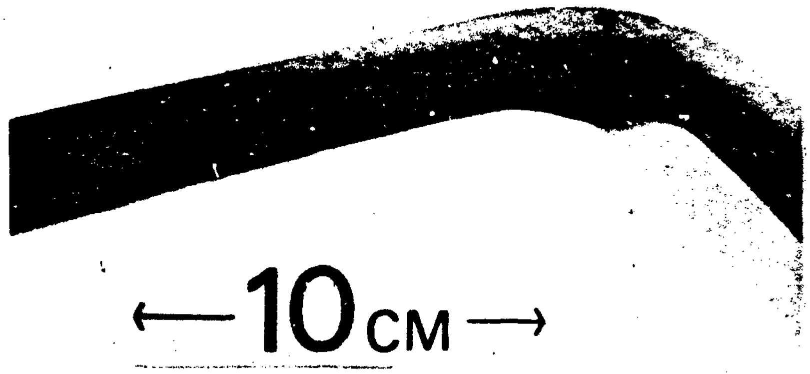

Figure 7 Crack at 90° bend in stainless steel desuperheater tube.

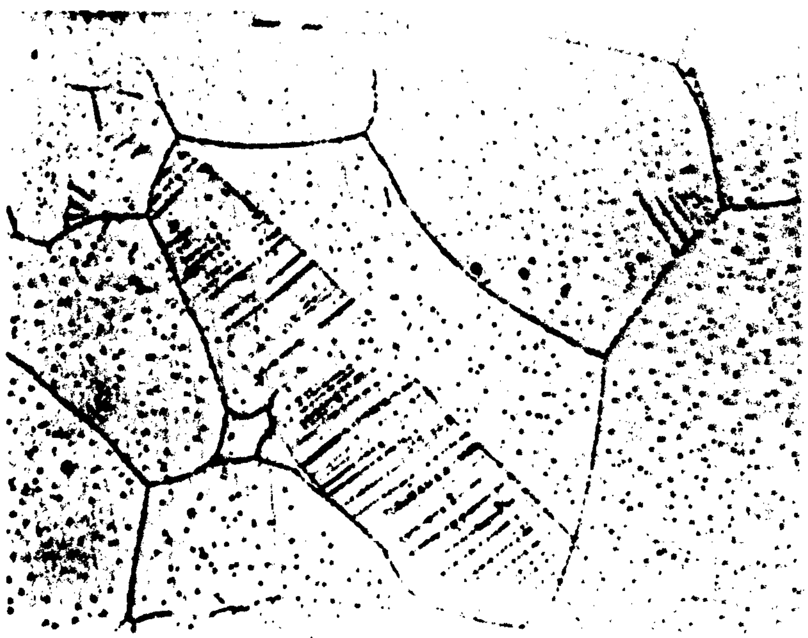

Figure 8 Metallograph of austenitic stainless steel desuperheater tube material showing carbide precipitation at grain boundaries and slip lines. X625

Although the operating temperature is only about 200°F, it appears that long term exposure at this temperature results in sensitization. Sensitization in combination with residual stress, increases stainless steel's susceptibility to stress corrosion cracking in the presence of chlorides[4]. Chlorides are a common impurity in marine boiler water and can be carried over in steam when their concentration becomes too high at separators. A metallographic examination showed an extensive intergranular fracture morphology (Figure 9).

It was recommended that the tube material be changed to a lower carbon stainless steel (UNS S30403) to reduce the risk of sensitization, and that a stress relief heat treatment be carried out after either welding or cold bending.

2.3 DDH 280's - Waste Heat and Auxiliary Boilers

The cores and coils of the waste heat and auxiliary boilers on the DDH 280 class ships have suffered from a variety of corrosion problems. The steam system on these gas turbine powered ships is required only for domestic purposes and is therefore considered to be of low priority importance.

The initial waste heat boiler cores were made of austenitic stainless steel (UNS S34700) tubes (Figure 10). In a very short period of time, these tubes suffered chloride stress corrosion cracking (Figure 11) and had to be replaced. As well as being a common impurity in boiler water, chlorides are also present in the marine atmosphere ingested by the waste heat producing gas turbine engines. The waste heat boiler cores were redesigned and fabricated with mild steel.

Both the coils of the auxiliary boiler, which have always been mild steel, and the new mild steel waste heat boiler cores were designed to use deoxygenated water. The feedtank they share, however, is open to the atmosphere and the water it suppies is rich in dissolved oxygen. The coils of the auxiliary boiler have had to be replaced approximately every two years since mild steel suffers from oxygen pitting corrosion attack[5] (Figure 12). It was not long before the new mild steel waste heat boiler cores were also suffering from pitting corrosion attack due to the presence of dissolved oxygen in the boiler water (Figure 13).

A decision has been made to replace the mild steel waste heat cores with ones made of a superior stainless steel (UNS N08028). Although this material will resist both oxygen pitting attack and chloride stress corrosion cracking, the auxiliary boiler coils will continue to corrode due to the presence of oxygen in the feedwater.

Water treatment trials were carried out using sodium sulfite as a dissolved oxygen scavenger, but the results were inconclusive because of coincidental equipment problems. Sodium sulfite should really be used as a residual dissolved oxygen scavenger in conjunction with a mechanical deaerator[6], but a mechanical deaerator cannot be installed because of space and weight limitations.

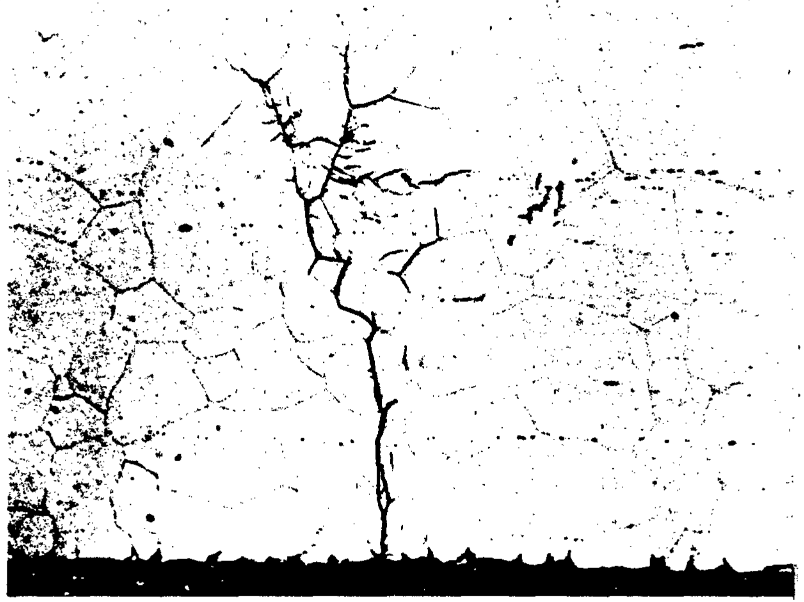

Figure 9 Metallograph of sensitized stainless steel desuperheater tube material showing resulting stress corrosion cracking. X156

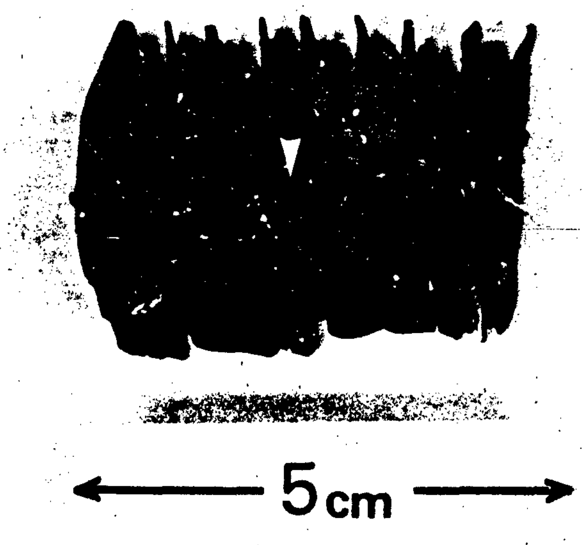

Figure 10 Original stainless steel waste heat core with cracks.

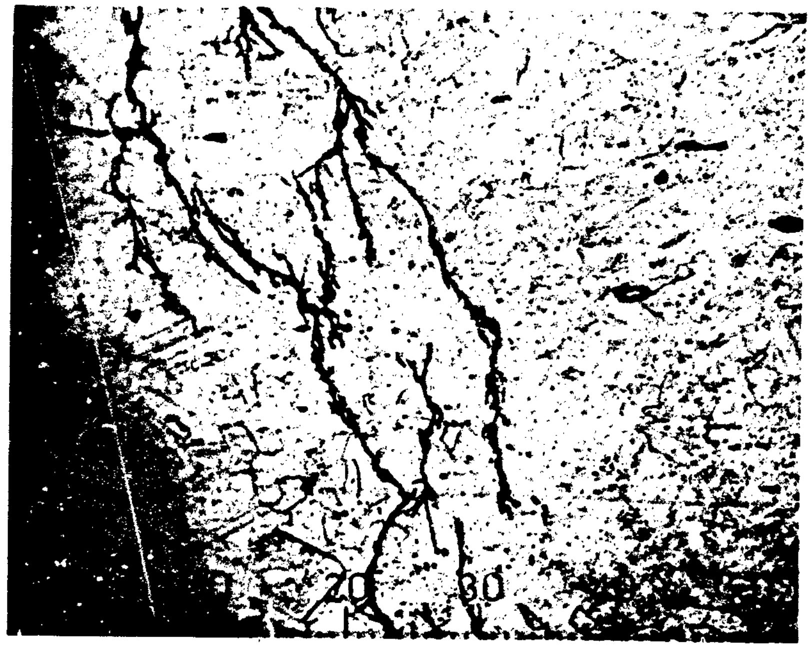

Figure 11 Metallograph of original austenitic stainless steel waste heat core material showing mixture of intergranular and transgranular chloride stress corrosion cracking. X125

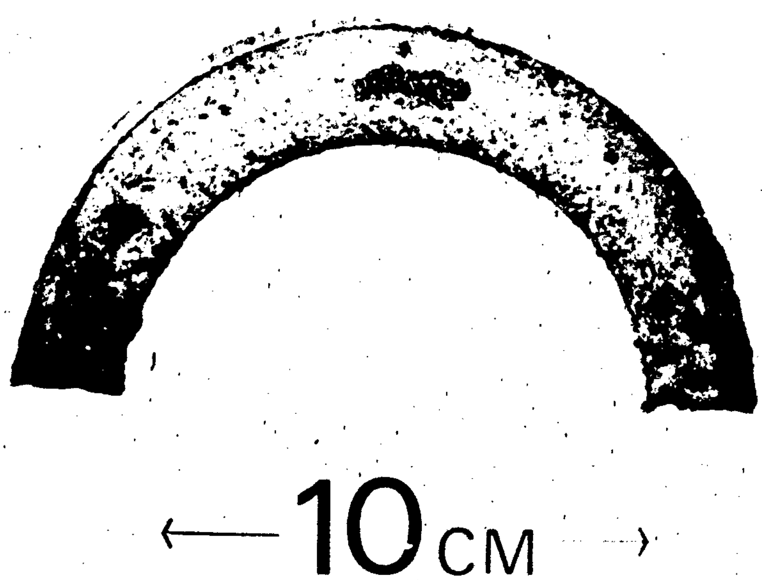

Figure 12 Sectioned mild steel auxiliary boiler coil showing oxygen pitting corrosion attack.

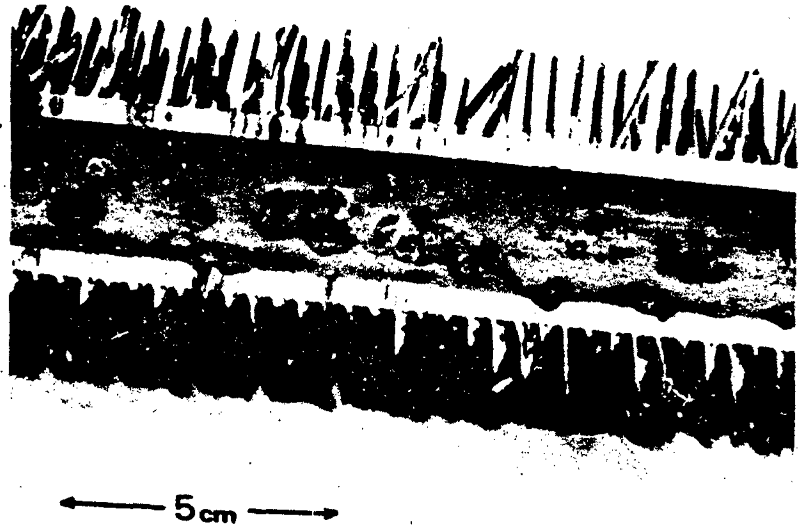

Figure 13 Sectioned mild steel waste heat boiler core showing oxygen pitting corrosion attack.

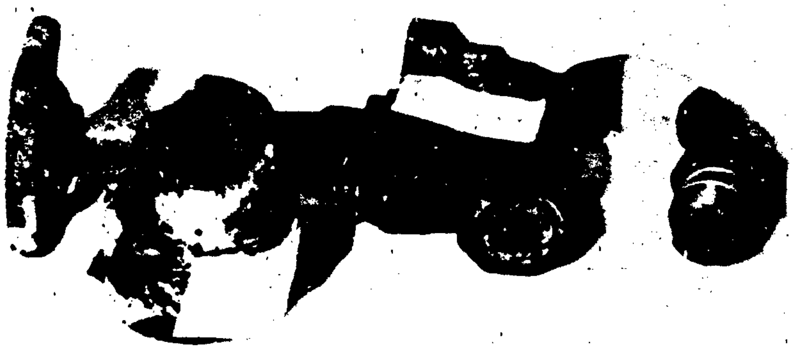

Figure 14 Failure of aluminum silicon bronze steam valve fitting by dealuminification.

Major engineering modifications of the feedwater supply and treatment system would have to take place before a satisfactory solution can be found.

2.4 Dealuminification of Aluminum Silicon Bronze

The DDH 280 Tribal Class destroyers contained a number of systems that used valves and fittings made of an aluminum silicon bronze alloy (UNS C95600). These systems included the low pressure steam lines, hydronic systems and some hot fresh water lines. The problem was found initially in the low pressure steam lines when a valve body snapped as the valve was being turned (Figure 14).

A metallographic examination showed that dealuminification attack[7] had almost penetrated the walls of the valve (Figure 15). The immediate recommendation was to replace all of the aluminum silicon bronze fittings with ones made of a material with greater corrosion resistance: leaded tin bronze (UNS C92200).

In the meantime, an industrial research contract was initiated to study the dealuminification susceptibility of this aluminum silicon bronze alloy. A corrective heat treatment was eventually found that reduced the alloy's susceptibility to corrosion attack. However, although the strength properties of the heat treated alloy were maintained the ductility was greatly reduced[8,9].

The replacement of the aluminum silicon bronze alloy with leaded tin bronze has proved to be successful to date.

3. SEAWATER SYSTEMS

Seawater is used in a variety of systems on naval vessels. Its primary function is for fighting shipboard fires. However, it is also used as cooling water in heat exchangers and condensers. Today most of the alloys used to carry seawater are copper based as they combine good corrosion resistance and antifouling properties with reasonable cost. However, some copper base alloys are more suitable than others and therefore care is needed to select the most appropriate alloy.

3.1 Firemain Brazolets

Brazolets are small castings that can be used to make perpendicular connections in firemain systems. Figure 16 shows a mockup of a section of a firemain with varying sizes of brazolets silver brazed to a large 90/10 copper nickel pipe. The brazolet is used in place of a heavier cast tee.

Approximately eight months after the launching of the first DDH 280 Tribal Class destroyer, the first failures of brazolets began to appear (Figure 17). The erosion corrosion problem seemed to be confined to the smaller brazolets (less than 2-1/2 inches in diameter).

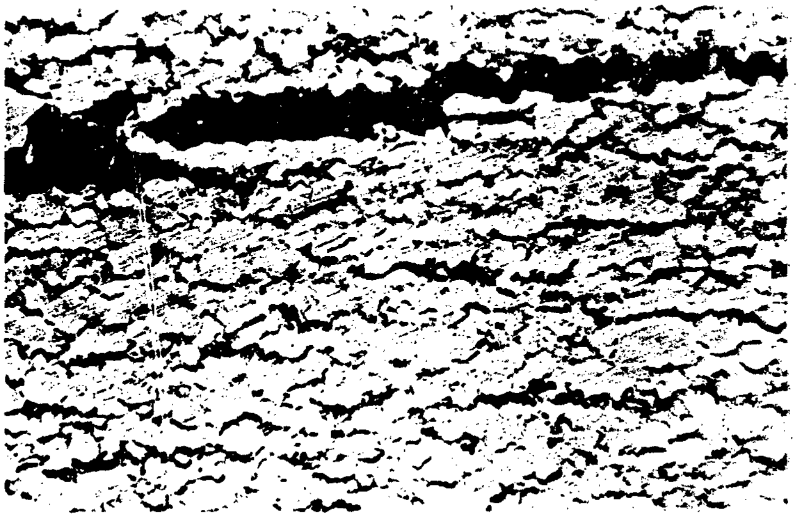

Figure 15 Metallograph of aluminum silicon bronze steam valve fitting showing dealuminification. X150

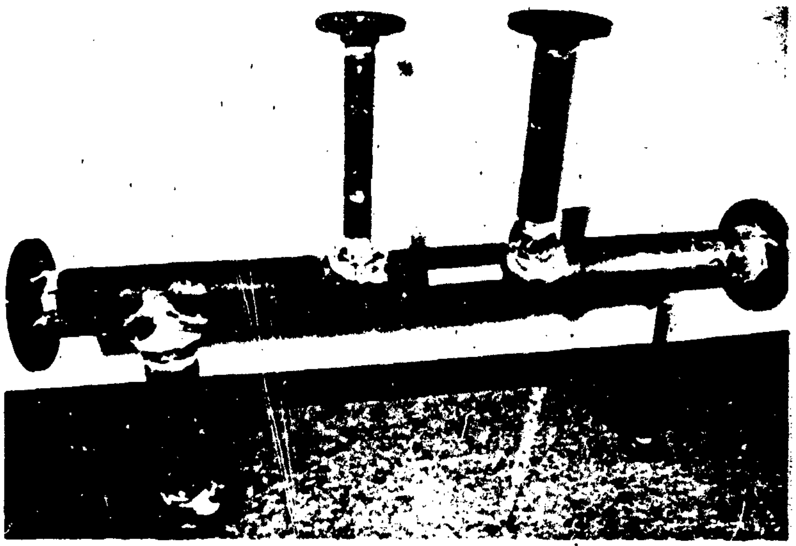

Figure 16 Mockup of firemain system showing leaded tin bronze brazolets and flanges, silver brazed to 90/10 copper nickel pipes.

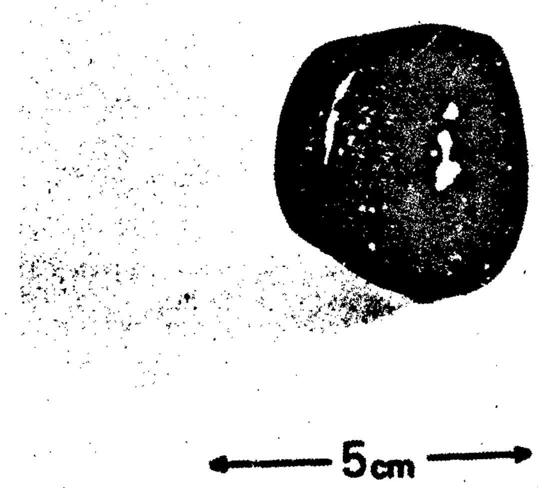

Figure 17 **Erosion corrosion of silicon maganese bronze brazolet.**

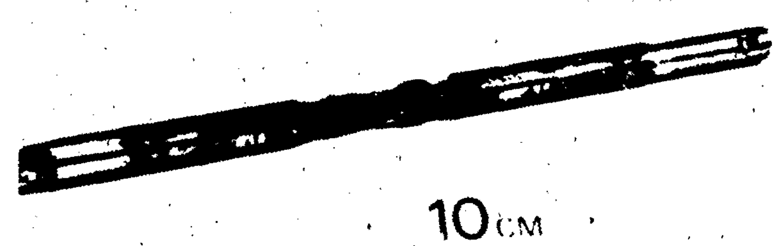

Figure 18 **Crevice corrosion attack of a stainless steel seawater pump shaft.**

A chemical analysis revealed that brazolets greater than 2-1/2 inches in diameter were made of leaded tin bronze (UNS C92200) while those less than 2-1/2 inches in diameter were made of silicon manganese bronze (UNS C87200). Silicon manganese bronze has been known to have poor resistance to erosion corrosion for over forty years[10]. All the brazolets less than 2-1/2 inches in diameter had to be replaced and it was a time consuming and costly undertaking.

3.2 Seawater Pump Shaft

A classic example of the dangerous use of components not intended for seawater applications is shown in Figure 18. This stainless steel (UNS S34700) pump shaft suffered from crevice corrosion attack and the most severe part of the attack was not visible with the pump impeller in place. The seriousness of this particular potential failure cannot be underestimated since the reliability of a pump is critical, especially for fire fighting.

It has generally been the policy of the Maritime Command for many years, to avoid the use of stainless steels in the marine environment. Experience has indicated that it is difficult to predict how a stainless steel will behave in a specific application. Because of the nature of the corrosion attack that occurs (crevice corrosion), there could possibly be no prior indication of a problem before the part fails[11].

More highly alloyed metals with superior crevice corrosion resistance such as Incoloy 825 (UNS N08825) or the monel nickel copper alloys (UNS N04400 and UNS N05500) would be suitable seawater pump shaft materials[12].

3.3 Firemain Pipe Corrosion

The two primary alloys used in the DDH 280 class firemain systems are 90/10 copper nickel (UNS C70600) (pipe) and leaded tin bronze (UNS C92200) (fittings). The Canadian Forces' experience with the 90/10 alloy has been favourable. There have been, however, a few areas in the DDH 280 class firemain systems that have experienced erosion corrosion damage (Figure 19).

The attack occurs at specific areas as a result of excessive turbulence[12]. Both the design of the firemain system and fabrication techniques influence the amount of water turbulence that is produced.

Another problem that has occurred in the past is the introduction of unsuitable and unspecified alloys into the firemain system. One example is a reducer which was required to connect a 5 inch pipe to a 2-1/2 inch pipe. Since a standard reducer could not be found in the stores system, one had to be fabricated in the shops. The material used was naval brass and the component lasted six months before dezincification penetrated the wall of the pipe (Figure 20).

3.4 Pump Impellers

Pump impellers in hull and firemain pumps frequently suffer extensive erosion corrosion and cavitation damage in periods as short as three months (Figures 21 and 22).

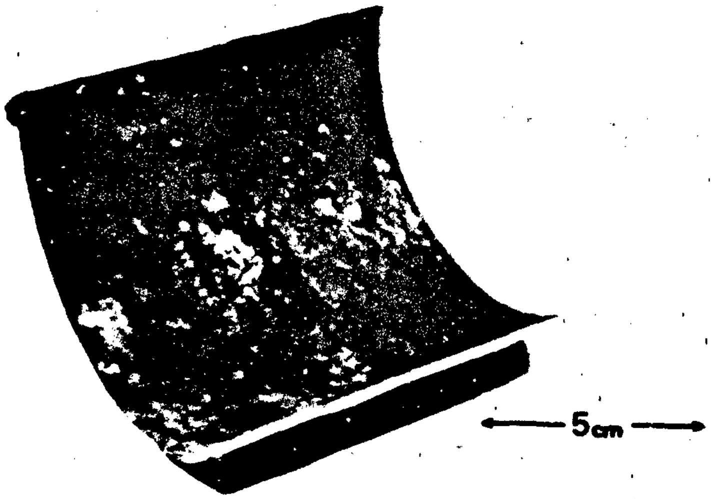

Figure 19   Erosion corrosion of 90/10 copper nickel pipe.

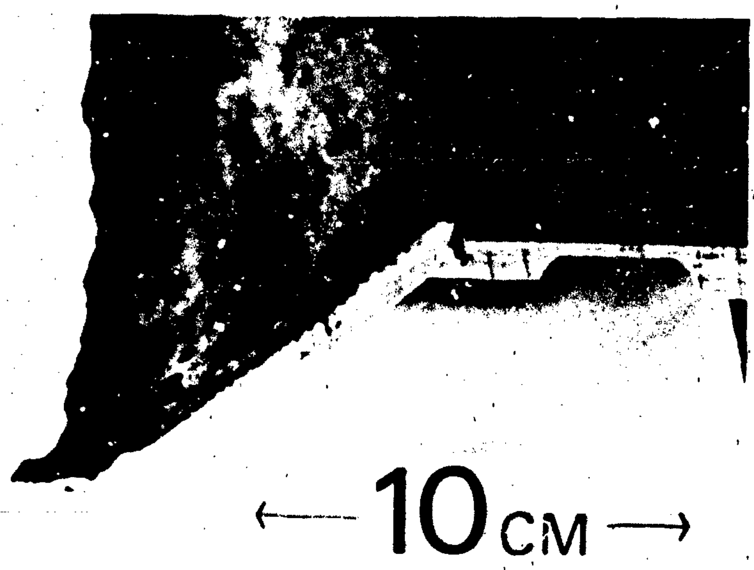

Figure 20   Dezincification of naval brass reducer.

Figure 21 **Erosion corrosion and cavitation damage of bronze pump impeller.**

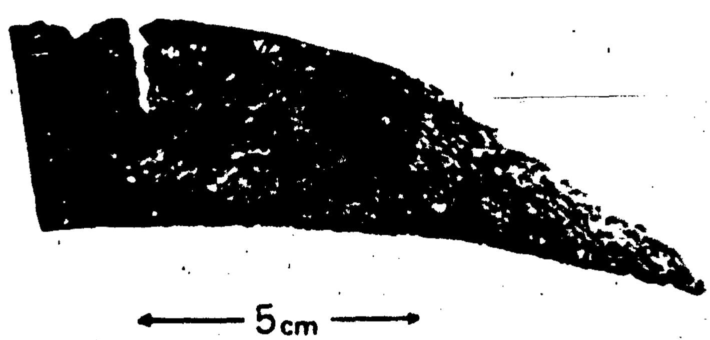

Figure 22 **Cavitation damage of bronze impeller vane.**

The most common alloy used for impellers is G Bronze (UNS C90300). A program to find materials with greater erosion corrosion resistance has identified a cast chromium modified 70/30 copper nickel alloy similar to wrought UNS C71900[14]. Engineering trials have begun with an impeller made of this alloy, installed in a hull and firemain pump.

In addition, since the serviceable life of an impeller is not only related to the type of material used, but also to the operating conditions of the pump itself, ships' engineers are encouraged to operate their pumps more efficiently in order to reduce cavitation.

4. GENERAL

This final section, deals with a variety of corrosion problems that have been found on Canadian Forces vessels.

4.1 Weld Corrosion in Bilges

An unexpected corrosion problem occurred on all four DDH 280 class destroyers. A shipyard worker noticed a stream of water coming from the bottom of one of the destroyers while it was in drydock. A subsequent survey of the bilge areas in the ship revealed areas where weld metal had corroded away completely (Figure 23). The areas around the weld metal were devoid of the inorganic zinc coating while further away, the coating seemed intact.

A laboratory investigation showed that the weld metal was anodic to the plate material. This difference in electrochemical potential combined with the large cathode to anode area ratio resulted in the galvanic attack of the weld metal[15].

The problem was solved by cleaning and recoating the bilge tanks and installing sufficient magnesium anodes to provide cathodic protection.

4.2 Fitting From Helo Hauldown System

A fitting from the helo hauldown system or "Bear Trap" failed as a helicopter was being winched down onto the flight deck of a destroyer. The middle link of the assembly fractured at the hole where a shear pin was located. The shear pin itself did not break (Figure 24).

The fitting was made of martensitic stainless steel (UNS S43100) with a hardness of HRC 40. A fractographic examination revealed an intergranular fracture morphology (Figure 25), while a polished metallographic cross section showed a sensitized microstructure characterized by carbide precipitation along former austenitic grain boundaries (Figure 26).

The link failed as a result of stress corrosion cracking. The susceptibility of the fitting to stress corrosion cracking was enhanced by its sensitized microstructure, which was the result of an incorrect heat treatment at the time of its manufacture[16].

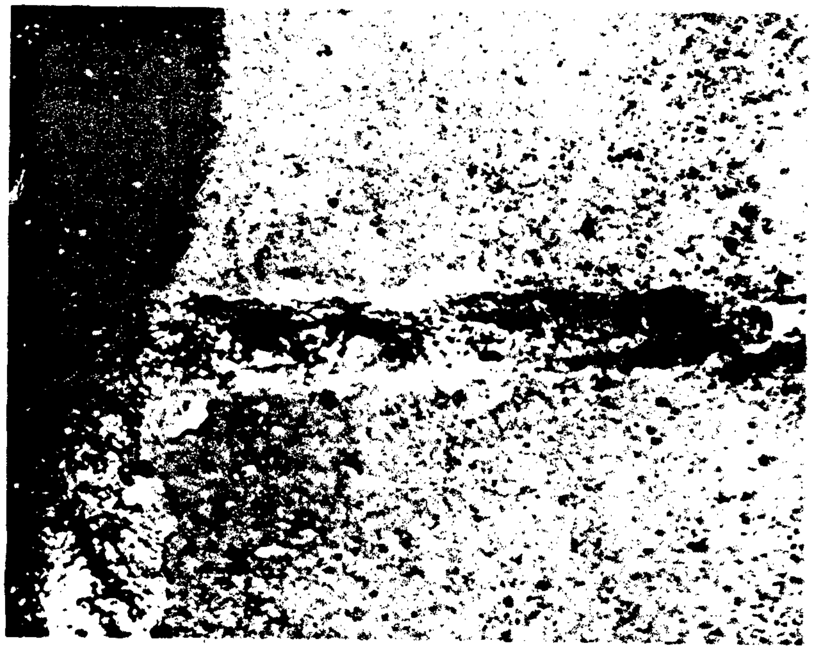

Figure 23 Galvanic corrosion of steel weld metal in bilges.

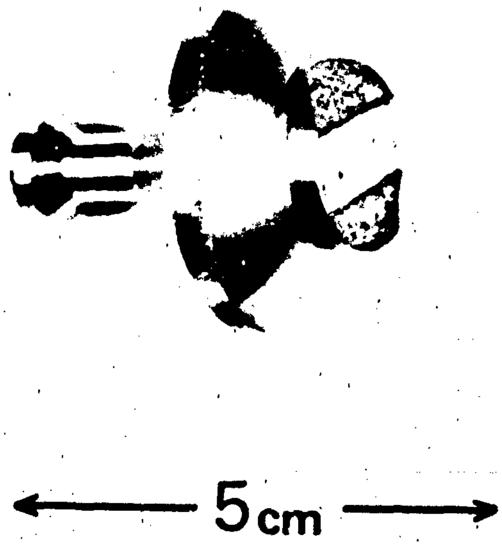

Figure 24 Failed martensitic stainless steel fitting from helo hauldown assembly.

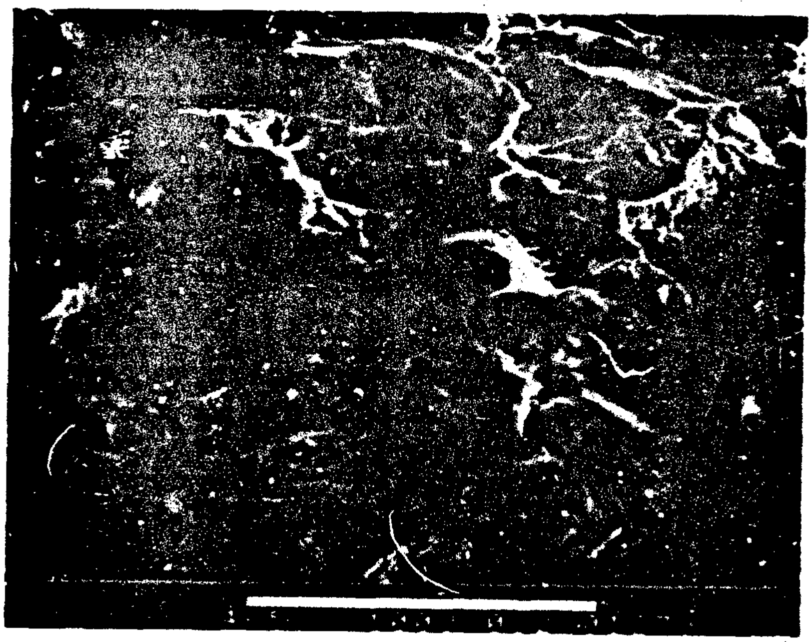

Figure 25 SEM micrograph of intergranular fracture surface of failed fitting shown in Figure 24. X465

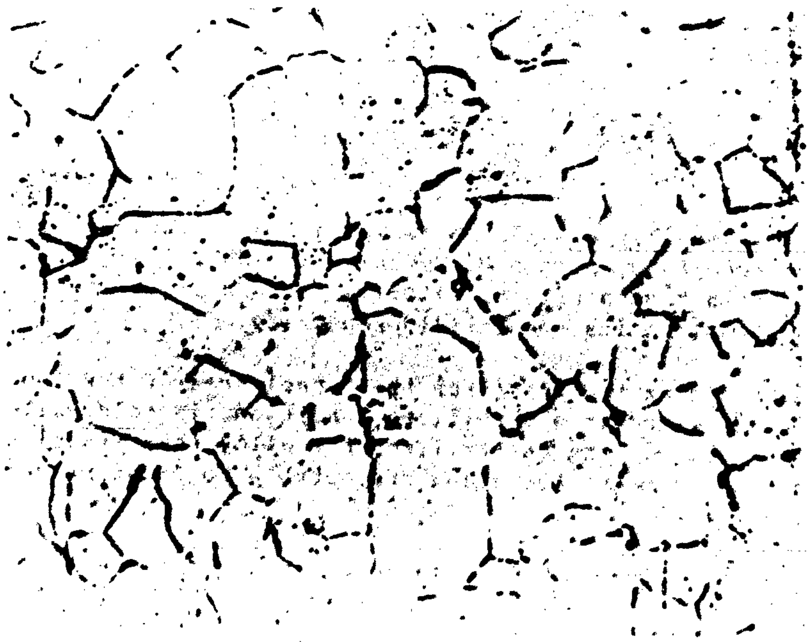

Figure 26 Metallograph of sensitized martensitic stainless steel fitting material showing carbide precipitation along former austenitic grain boundaries. X400

Based on DREA's recommendation, all fittings were removed from service and given a corrective heat treatment. There have been no further failures to date.

4.3 Pelican Hooks

The pelican hook is part of the quick release mechanism for the twenty man life rafts carried on board Canadian Forces vessels. A hook on one of the life rafts failed unexpectedly (Figure 27).

A chemical analysis of the two parts of the hook showed that one part was made of a manganese bronze alloy (UNS C86500) while the part that failed was made of a higher strength manganese bronze alloy (UNS C86300). A metallographic examination of each part revealed microstructures consistent with the chemical compositions. The UNS C86500 alloy had alpha needles in a beta matrix (HRB 75) while the UNS C86300 alloy had very little alpha phase in the beta matrix (HRB 98) (Figures 28 and 29). The fracture morphology of the surface was totally intergranular.

The hook failed as a result of stress corrosion cracking of the high strength alloy (UNS C86300)[17]. This alloy is never recommended for use in a marine environment. An in situ examination was made of all hooks using eddy current instrumentation, to see if other hooks were manufactured from the two different alloys.

4.4 Corrosion of Aluminum Landing Craft Hulls

Severe corrosion has occurred on all of the aluminum hulled landing craft. However, the only area which has been attacked is the aft lower hull panels above the shaft and propellers (Figure 30).

The hull material is the aluminum alloy UNS A95083 in the H321 condition. Figure 31 shows the layered corrosion attack typical of exfoliation.

The aluminum alloy UNS A95083 is a non heat treatable alloy that acquires its strength by strain hardening. The H321 designation indicates that, after strain hardening, the alloy is given a low temperature thermal treatment to stabilize its mechanical properties.

When fabricating the plate for the tunnel area of the landing craft the plate which is received in a stabilized condition, is cold rolled. It is suspected that cold rolling destabilizes the alloy thus inducing a gradual aging process, which makes the alloy susceptable to exfoliation corrosion[18].

A project has been initiated to determine if this destabilization does occur and whether it can be halted with a second thermal treatment.

5. SUMMARY

The key to combating corrosion in the Canadian Forces requires an improvement in two areas, education and communication. Failure analysis is very important but of equal importance is corrosion training. Corrosion training should be given as extensively as possible. The more personnel aware of even the elementary fundamentals, the more chances there are of preventing what can only be described as the "careless" corrosion problem. Recognizing that training is costly and that it would be impractical to educate everyone, it should be possible to ensure that all personnel are aware of who they can go to for assistance and that they are encouraged to do so.

The other aspect involving corrosion control is not scientific but can be as equally important as education: communication. The sequence of reporting of problems, failure analyses and the implementation of recommendations could be greatly assisted with an improvement in communications. All personnel must be informed of the role they have to play, who are the immediate team players and what are their responsibilities.

All of the corrosion problems discussed in this paper can be eliminated or reduced a significant degree using modern corrosion control practices. These case histories reflect some of the problem areas identified in the introduction and can also be seperated into the two broad problem areas of education and communication. The corrosion in the waste heat and auxilary boilers could have been avoided in the initial design of the systems. The stainless steel pump shaft, which suffered from crevice corrosion, is an excellent example of a piece of equipment that is satisfactory for most industrial applications but is unsuitable for use in a marine environment. Finally the example of the dezincification of the naval brass reducer is typical of the problems that are encountered when material substitutions are made without consultation.

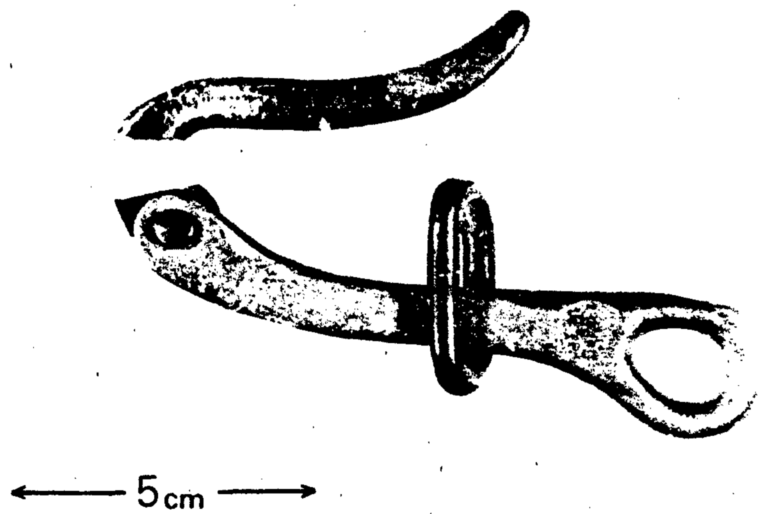

Figure 27 Failed manganese bronze pelican hook from twenty man life raft.

Figure 28 Metallograph of lower strength manganese bronze (UNS C86500) pelican hook material showing alpha needles in beta matrix. X310

Figure 29 Metallograph of failed higher strength manganese bronze (UNS C86300) pelican hook material showing small amounts of alpha phase in beta matrix and intergranular fracture morphology. X310

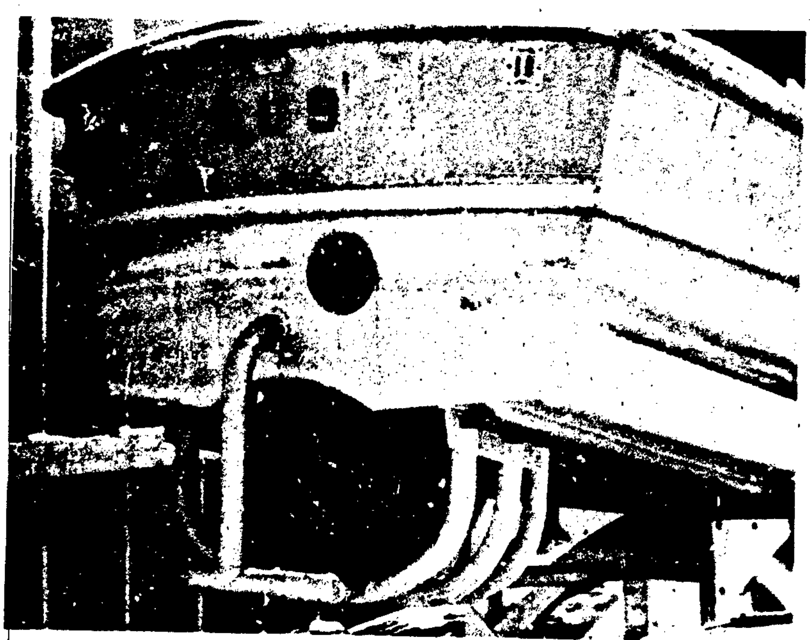

Figure 30 Corrosion attack in tunnel area of aluminum hulled landing craft.

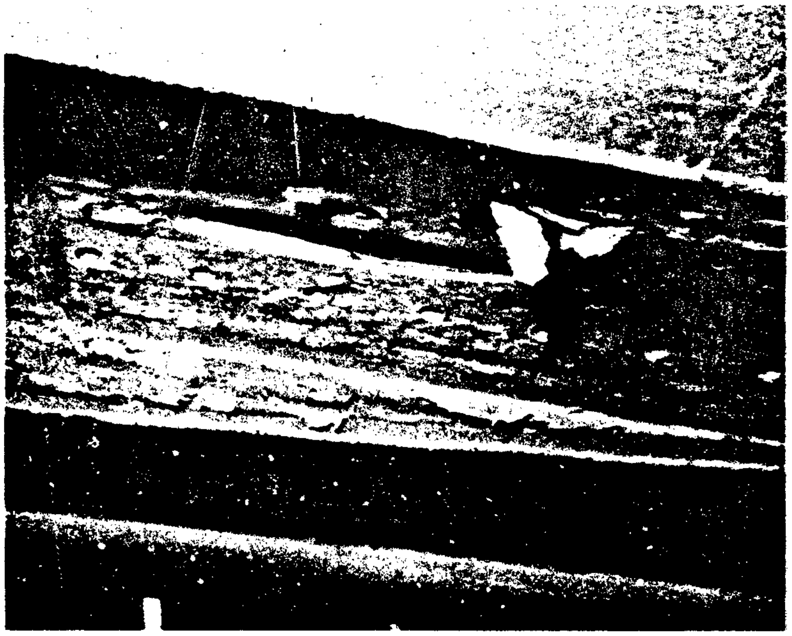

Figure 31 Layered attack typical of exfoliation corrosion of aluminum alloys.

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Investigations of corrosion related failures that have taken place on Canadian naval ships are described. The investigations are divided into three categories: Machinery, Seawater Systems and General. The Machinery category includes examples of corrosion problems with desuperheater tubes, gas turbine engine fuel manifolds, and waste heat and auxiliary boilers. The Seawater Systems category describes the erosion corrosion of copper nickel pipes and pump impellers, and the crevice corrosion of a pump shaft. The General category includes corrosion problems with hulls and fasteners.

All of the corrosion problems described can be eliminated or reduced a significant degree using modern corrosion control practices.

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